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Gravity anomalies in the Blue Mountains, eastern Jamaica

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ABSTRACT

Data from 26 new gravity stations in the Blue Mountains are presented and compiled with previous stations into maps of free-air and Bouguer gravity anomalies of eastern Jamaica. The maximum positive free-air anomaly exceeds 300 mgal and the maximum positive Bouguer anomaly exceeds 155 mgal. The latter is displaced to the east relative to the former and is situated over blueschists which are part of a belt of dense metamorphic and igneous basic rocks exposed along the Plantain Garden Fault. A two-dimensional structure model of the upper 10 km of the crust is discussed as a possible explanation of the WNW trending Bouguer anomaly. This model emphasizes the importance of major vertical displacement across the Plantain Garden Fault. The correlation between major on-land positive Bouguer anomalies and sites of differential Quaternary uplift in parts of Jamaica, Cuba and Haiti suggests that land associated with these anomalies is rising.

RESUMEN

Se presentan datos de veintiseis (26) nuevas estaciones de gravedad en las Blue Mountains y se compilan con estaciones previas en mapas de anomalías gravimétricas de Bouguer y de aire libre de la región oriental de Jamaica. La máxima anomalía positiva de aire libre excede los 300 mgal y la máxima anomalía positiva de Bouguer excede los 155 mgal. Esta última está desplazada hacia el este, con forma relativa a la anterior y está situada sobre esquistos azules, los cuales son parte de una franja de rocas ígneas básicas y metamórficas, muy densas, expuestas a lo largo de la Falla Plantain Garden. Un modelo estructural bi-dimensional de los 10 km superiores de la corteza se discute como una posible explicación de la anomalía de Bouguer con rumbo W—NW. Este modelo enfatiza la importancia de un desplazamiento vertical principal, a través de la Falla Plantain Garden. La correlación entre las principales anomalías de Bouguer positivas, en tierra y los sitios de levantamientos diferenciales del Cuaternario en partes de Jamaica, Cuba, y Haití, sugiere que el terreno asociado con esas anomalías se está levantando.

INTRODUCTION

The history of the measurement of gravity in Jamaica began in 1957 with the establishment of about 100 stations by C.H.G. Oldham of the California Exploration Co. The measurements were supplemented by a further 100 stations in 1960 by R.F. Geller of the Inter-American Geologic Survey. A much more complete survey of the whole island was carried out in 1964 and 1966 by F.M. Andrew of the Institute of Geological Sciences. This work established 752 stations and the published results (Andrew, 1969) remain the standard reference to the subject.

Andrew published two anomaly maps, but made no attempt to interpret them in terms of geological structure. There have been two developments since Andrew's survey which modify that presentation of the gravity field in eastern Jamaica. Efforts have been made by the staff of the Department of Geology, University of the West Indies to measure gravity in the more inaccessible parts of the Blue Mountains. An additional 26 stations have been established which help to define the shape and magnitude of the Blue Mountain positive Bouguer anomaly. Also over the last ten years there has been a major improvement in our knowledge of the geology of the Blue Mountains. In particular, along the faulted southern boundary of the Blue Mountain Inlier the outcrop pattern of a number of metamorphic and igneous lithologies has been mapped (Figure 1). In general these rocks are of basic composition and have a high specific gravity. The geologic significance of these rocks is reported elsewhere (Draper *et al.*, 1976; Draper, 1979; Horsfield and Roobol, 1974; Wadge *et al.*, 1980). The significance of these dense rocks to the gravity field of eastern Jamaica forms the basis of this paper.

NEW GRAVITY MEASUREMENTS

The locations of the new gravity stations are shown in Figure 2 and the gravity values shown in Table 1. The new stations are mainly on the southern side of the Grand Ridge

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of the Blue Mountains and have been established where new forestry roads and helicopter access were available. To the north of the Grand Ridge there is still a large area with no coverage. It is hoped that this and other gaps will eventually be filled in.

The instrument used was a Worden gravimeter (Prospector Model 112). Station location is substantially improved relative to the Andrew survey because of the availability of 1:12,500 topographic maps of the whole island. Where possible new stations were located at photogrammetric spot heights and calibrated with a Paulin Terra altimeter. All the new stations were correlated with stations within the Andrew network. Instrumental drift was generally less than 0.1 mgal/day.

ANOMALY MAPS

Two new gravity anomaly maps of eastern Jamaica are presented in Figures 3 and 4. Both free-air and Bouguer anomalies are positive over the whole area. Datum for the Bouguer and terrain corrections is sea level and a standard density of 2,670 kg m^{-3} was used for all the new stations. Andrew did not use this single density in his Bouguer corrections but used a variety of densities for each station according to his understanding of the geology and the densities of the main lithologies. He was not aware, however, of the high densities of the rocks shown in Figure 1, which are apparent in Table 2. Hence, no account was taken of the effect of these high density rocks on the Bouguer correction above sea-level. Strictly speaking there are slight differences between the new stations and the Andrew anomalies which have been overlooked in compiling the Bouguer anomaly map. These differences will eventually be removed but for the present purposes of examining the gross structure of the Bouguer anomaly (with almost 100 mgal relief on land) the magnitude of the error involved (about 2 mgals) is sufficiently small to ignore.

Important differences can be observed between the free-air and Bouguer anomaly maps. The free-air anomaly map is dominated by the high relief of the Grand Ridge (about 2300 m) which produces a maximum positive anomaly of over 300 mgals. The WNW trend of the main anomaly does not extend further westward than the Port Royal Mountains which lie between Kingston and Annotto Bay. The Bouguer positive anomaly of the Blue Mountains is apparently broader, displaced further to the north, and does extend west of Annotto Bay (Figure 4). The peak of the Bouguer anomaly exceeds 155 mgal and is found further east than the highest mountains of the Grand Ridge over the surface outcrops of the dense blueschists. Perpendicular to its length the anomaly is asymmetrical with much steeper gradients to the south and much higher values (about 100 mgals) at the north coast than at the south (about 70 mgals).

INTERPRETATION OF THE ANOMALIES

The saturated bulk densities of representative specimens from the main lithologies of eastern Jamaica are listed in Table 2. The main deficiency of this list is the lack of representatives of Tertiary igneous rocks, primarily the Newcastle dacites of the Wagwater Belt. The higher grade metamorphic rocks of the Westphalia Schists are also absent from this list but are believed to be of similarly high density as the blueschists. Compared to the Tertiary rocks the basic Cretaceous rocks are over 300 kg m^{-3} more dense. The magnitude of the difference in density between the Cretaceous basic rocks and the clastic and intermediate volcanic rocks of Cretaceous age is almost as great.

The correlation of the surface outcrops of these dense rocks with the maximum of the Bouguer anomaly indicates that these rocks are primarily responsible for the Blue Mountain positive anomaly. We suggest that their configuration at depth controls the shape of that anomaly.

Figure 5 displays the schematic relationships of the main rock units in eastern Jamaica drawn onto a N–S profile (line A–A′ in figure 4), together with the relevant values of density. In detail the structure is very much more complex than shown here (Draper, 1979, Wadge and Draper, 1978, Krijnen and Lee Chin, 1978, Kemp, 1971) but the section displays the two most important features of eastern Jamaican geology. These are the basic antiformal structure and the major vertical displacement of the Plantain Garden Fault which juxtaposes the Tertiary rocks with the structurally lowest parts of the Cretaceous inlier.

We have attempted to apply these simple geological facts to models of density contrast within the upper crust that are compatible with the observed Bouguer anomaly. Unfortunately, there is no deep seismic data or even deep boreholes for control. Figure 6 demonstrates one such two dimensional model based on the AA′ profile. Four units of different rock density have been used. The Tertiary rocks have been assigned a value of 2,600 kg/m^3. An average value for the Cretaceous sedimentary and intermediate volcanic rocks of 2,650 kg/m^3 is a necessary approximation as the detailed structure and density variation of these rocks are poorly known. 2,700 kg/m^3 is the value for the granodiorite intrusion and 2,930 kg/m^3 is an averaged estimate for the basic Cretaceous rocks. This latter figure may be too high if there are appreciable amounts of serpentinite at depth, and of course the models are most sensitive to the choice of this value. The assumption of linearity of the Blue Mountain anomaly in the third dimension is reasonable in the WNW direction and less so in the ESE direction.

The fit between the anomaly and the model in figure 6 is reasonably good. The main elements of this model are the large vertical relief (>5 km) in the Cretaceous dense "basement" along the Plantain Garden Fault and the much shallower depths to this interface over the northern Blue Mountains (<4 km) compared to southern Jamaica. Variations of the model involving a less dense "basement" necessitate greater relief of the central anomalous core relative to the overlying lighter Cretaceous and Tertiary rocks.

DISCUSSION

The model used in figure 6 accounts for the shape of the on-land Bouguer anomaly in terms of density variations within the upper 10 km of the crust. Deep crustal structure, in particular the depth to the Moho, is probably uniform under eastern Jamaica. A figure of 20 km to the Moho is usually assumed for Jamaica (Arden, 1969) based on seismic refraction profiles in the Jamaica Passage and on the Nicaraguan Rise (Ewing *et al.*, 1960). No attempt has been made to derive a complete structure model involving crust/mantle relief. The short length of the profile and the lack of additional constraints preclude this. However, it is worthwhile considering the significance of Blue Mountain anomaly in terms of the wider regional picture.

The seismic sections of Ewing *et al.*, (1960) have been correlated with the regional geology of the Nicaraguan Rise by Perfit and Heezen (1978, Figure 9A). Paleogene carbonates and volcanics are correlated with the 5.4–5.5 km s^{-1} layer immediately overlying the 10–15 km thick layer with velocities in the range 6.2–6.7 km s^{-1} which is presumed to represent the Cretaceous rocks. However, in eastern Jamaica this seismic discontinuity is best represented by the density contrast between the 2,930 kg/m^3 and 2,650 kg/m^3 units of the gravity model. This correlation between offshore seismic structure and the gravity model of eastern Jamaica is depicted in Figure 7.

Andrew (1969, Figure 7) compiled an isostatic anomaly map (compensation depth 30 km) based on the Airy-Heiskanen system from his Jamaican data. The positive isostatic anomalies are almost identical in shape to the Bouguer anomalies for the whole island and reach in excess of 70 mgals over the Blue Mountains. On the basis of this Bowin (1976) concluded that the whole island was under-compensated. Bowin's (1968) study of the gravity field of the Cayman Trough also revealed several small submarine structures that were out of isostatic equilibrium, some with mass deficiences, some with mass excesses. These structures have widths similar to that of the Blue Mountain anomaly, about 40 km. The density value assigned to the 6.2–6.7 km s^{-1} layer by Bowin in his structure model of the Cayman Trough is 2,800 kg m^{-3} (Bowin, 1968, figure 6). This is 130 kg m^{-3} less than the value used in the Blue Mountain model, and emphasizes the need to have dense crustal rocks at high levels beneath eastern Jamaica to explain such high positive anomalies on land.

The regional significance of the Plantain Garden Fault and its extensions has become apparent in the last few years. The continuity of the Rio Minho-Crawle River-Cavaliers-Plantain Garden Fault system traversing the whole length of the island was suggested by Horsfield (1974) and Burke *et al.*, (1980, Figure 8). Offshore in the Jamaica Passage to the east the fault can be traced in the bathymetry forming the northern boundary to the Morant Ridge and the Navassa Basins (Horsfield and Robinson, 1974; Goreau, unpub. data, Figure 3). This feature comes ashore in the Southern Peninsula of Haiti as the Presque'ile du Sud Fault and can then be traced as far as Port au Prince. The total length of this curving fault system is about 600 km and it is a major component of the tectonics of the northern boundary of the Caribbean Plate. Movement on these faults can be mainly related to Cenozoic development of the Cayman spreading center to the north though there is no present day seismicity associated with them.

Whilst there is no seismic evidence for the uplift of the Blue Mountains along the present day Plantain Garden Fault there is some evidence for Pleistocene tectonic uplift in Jamaica which may be of relevance to the gravity anomalies. Horsfield (1973, 1975) has documented the existence of several raised marine terraces of the north coast of Jamaica which he interpreted as being principally due to differential Quaternary tectonic uplift. The two best examples of these multiple terraces are at Oracabessa and Negril (figure 8) where there are large gradients in the Bouguer and isostatic anomalies cutting the coast at these points (Andrew, 1969, Figures 6,7). This implies that differential uplift during the last few hundred thousand years may be associated with the regions exhibiting steep gradients on the flanks of positive gravity anomalies. This association holds for some of the other land-based positive anomalies around the eastern Cayman Trough (Figure 8); Oriente Province, Cuba, the Northwest Peninsula and the Southern Peninsula of Haiti. Our interpretation of this is that the dense Cretaceous core of the Blue Mountains is still rising under the current regime of intraplate stresses.

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Table 1

Gravity values and station location data for the gravity stations shown in Figure 2. *Station 509 is the same station as used by Andrew. A more accurate grid reference has been used which slightly changes the value of observed gravity.

Station	Grid Reference		Heigh Above Sea-Level (Feet)	Observed Gravity (MGAL)	Free-Air Anomaly (MGAL)	Bouguer Anomaly (MGAL)
B	7297	3884	369	978639.7	135.2	129.5
C	7256	3915	846	978619.6	159.4	138.9
D	7229	3933	2461	978518.7	210.1	140.4
E	7212	3977	2901	978509.4	241.6	153.9
F	7214	4021	3092	978503.6	253.2	158.5
G	7248	4051	3395	978477.6	255.2	155.7
H	7326	3827	328	978626.0	118.4	110.3
UWI 57	6591	4277	2820	978486.7	207.2	119.3
UWI 58	6640	4291	3430	978455.2	232.9	122.9
UWI 59	6670	4267	4543	978382.3	265.1	121.4
UWI 60	6699	4259	4770	978370.9	275.1	124.2
UWI 61	6711	4283	5410	978326.6	290.6	123.8
UWI 62	6712	4292	5495	978321.3	293.2	123.2
UWI 63	6710	4322	5979	978283.4	300.1	119.8
UWI 64	6647	4272	4000	978415.3	246.9	119.2
UWI 65	6629	4250	3641	978436.8	235.1	118.6
UWI 66	6649	4217	3618	978436.3	232.9	116.8
UWI 67	6684	4227	4250	978403.2	259.0	124.7
UWI 68	6579	4312	3500	978447.5	231.4	117.8
UWI 69	6819	4055	2168	978522.0	180.3	113.5
UWI 70	6811	4112	3364	978467.9	237.9	133.3
UWI 71	6784	4155	4049	978415.1	249.0	123.1
UWI 72	6833	4160	4056	978425.9	260.3	134.0
UWI 73	6869	4164	4495	978394.7	270.3	129.8
UWI 74	6709	4091	2040	978525.7	171.5	107.7
UWI 52	6896	4255	3001	978491.1	228.6	138.8
509	6542	4318	3404	978446.9	221.7	117.2

Table 2

Saturated bulk rock densities of representative samples from the main lithological types in eastern Jamaica.

Rock Type	Average Density kg m^{-3}	Number of Samples	Range kg m^{-3}
Blueschists	2990	10	3080–2760
Basalts	2820	5	2930–2710
Granodiorite	2720	5	2750–2689
Cretaceous sandstones, shales, tuffs	2620	5	2690–2550
Cretaceous conglomerates	2710	4	2850–2540
Tertiary sandstones shales	2590	4	2680–2500
Tertiary limestones	2610	15	2670–2510

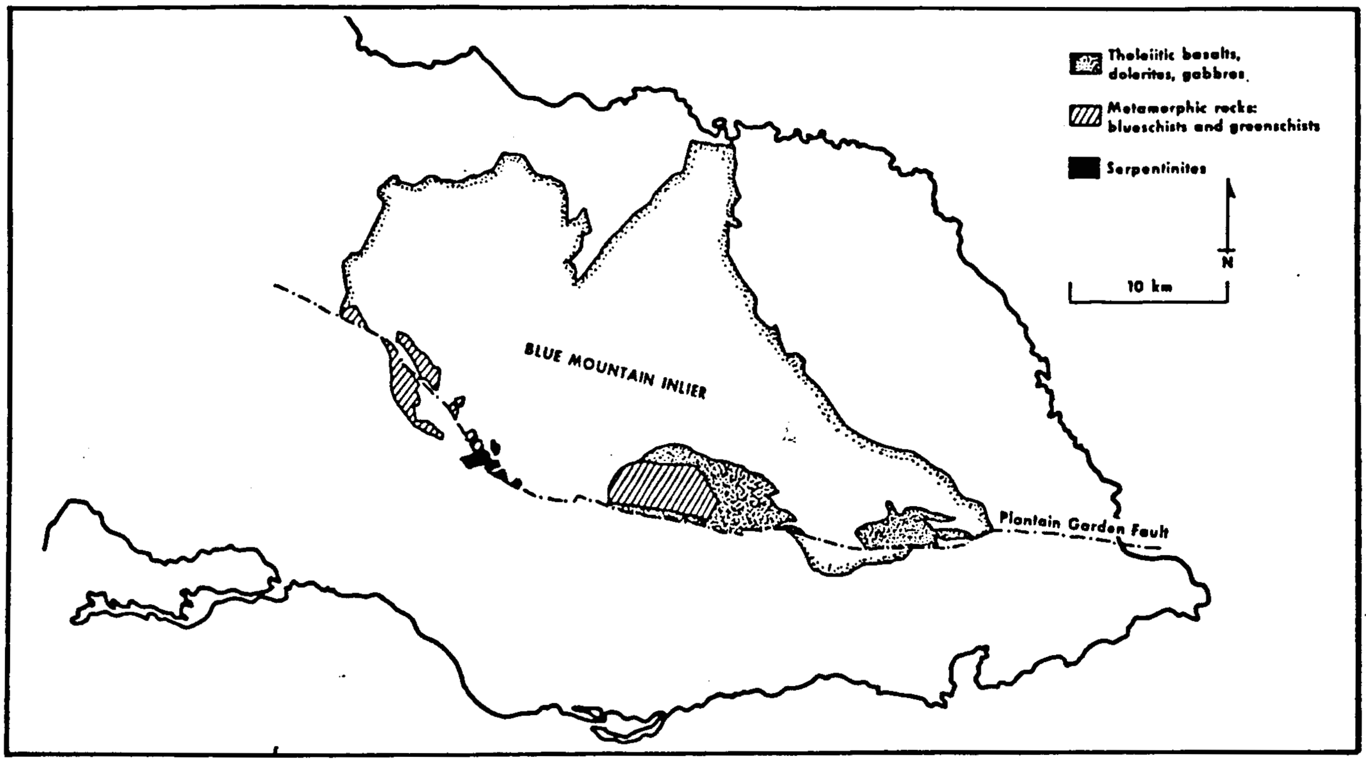

Figure 1. Map of eastern Jamaica showing the outline of the Cretaceous rocks of the Blue Mountain Inlier and the dense, basic igneous and metamorphic rocks distributed along the Plantain Garden Fault.

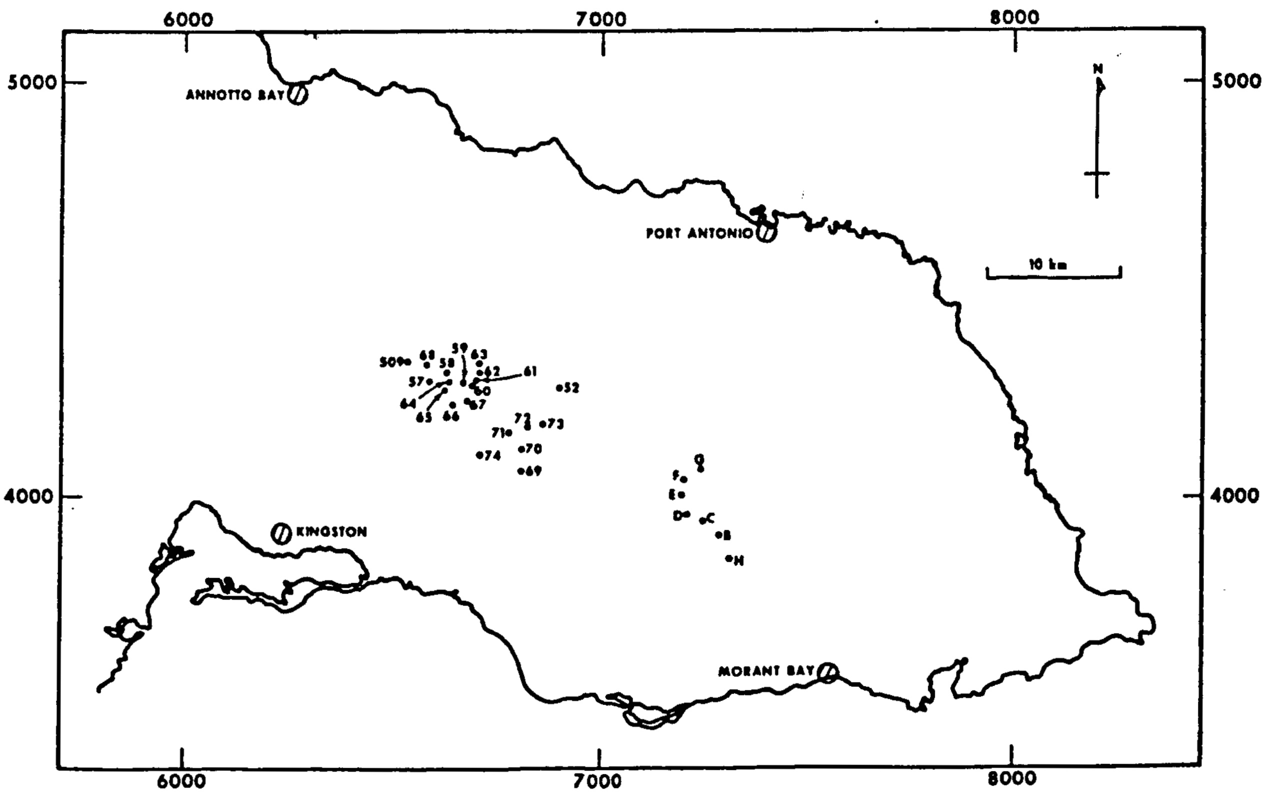

Figure 2. New gravity stations in the Blue Mountains.

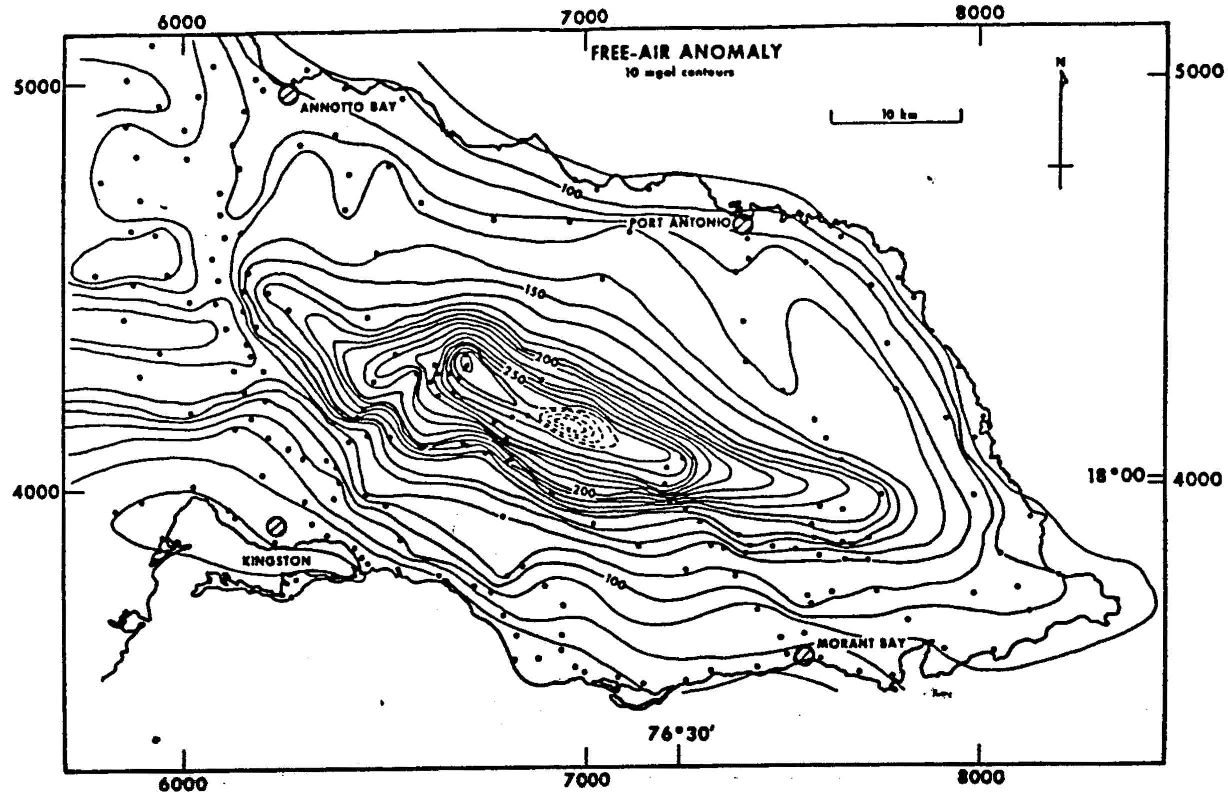

Figure 3. Free-air gravity anomaly map of eastern Jamaica. Data from Andrew (1969) and this paper. A speculative maximum anomaly is shown as dashed contours over the highest part of the Blue Mountains.

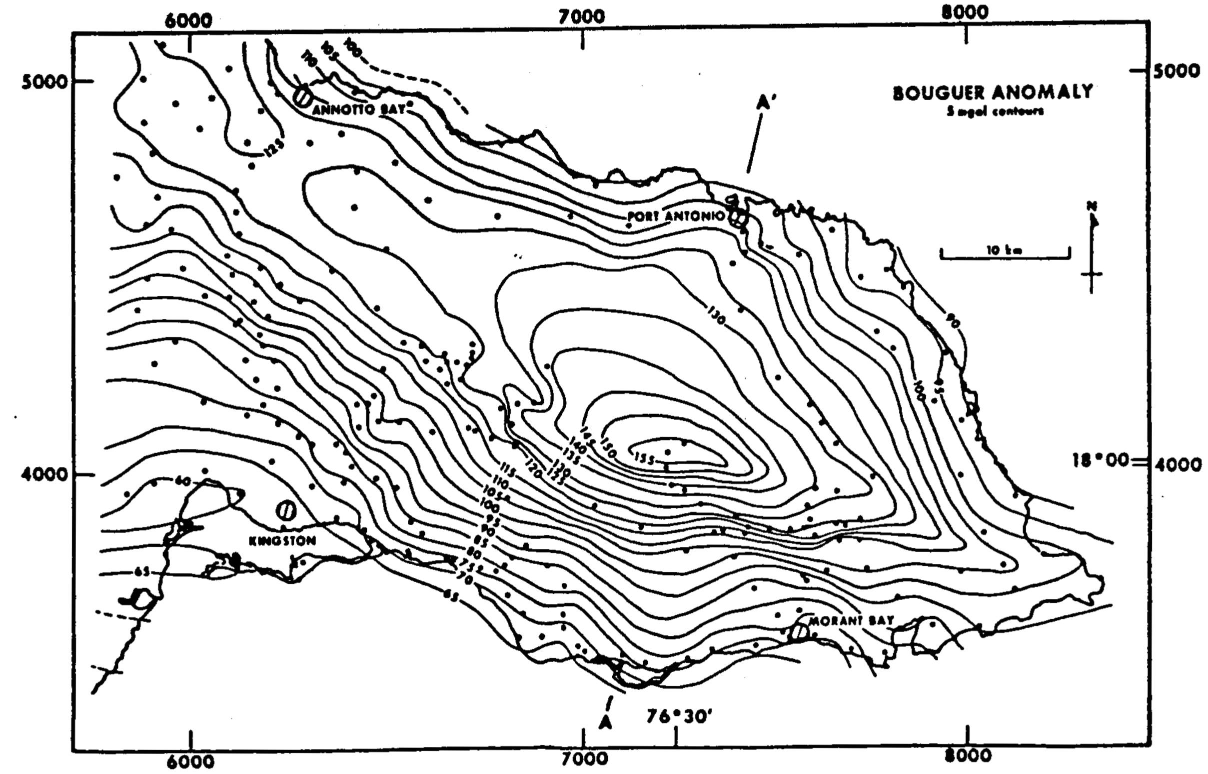

Figure 4. Bouguer gravity anomaly map of eastern Jamaica. Data from Andrew (1969) and this paper.

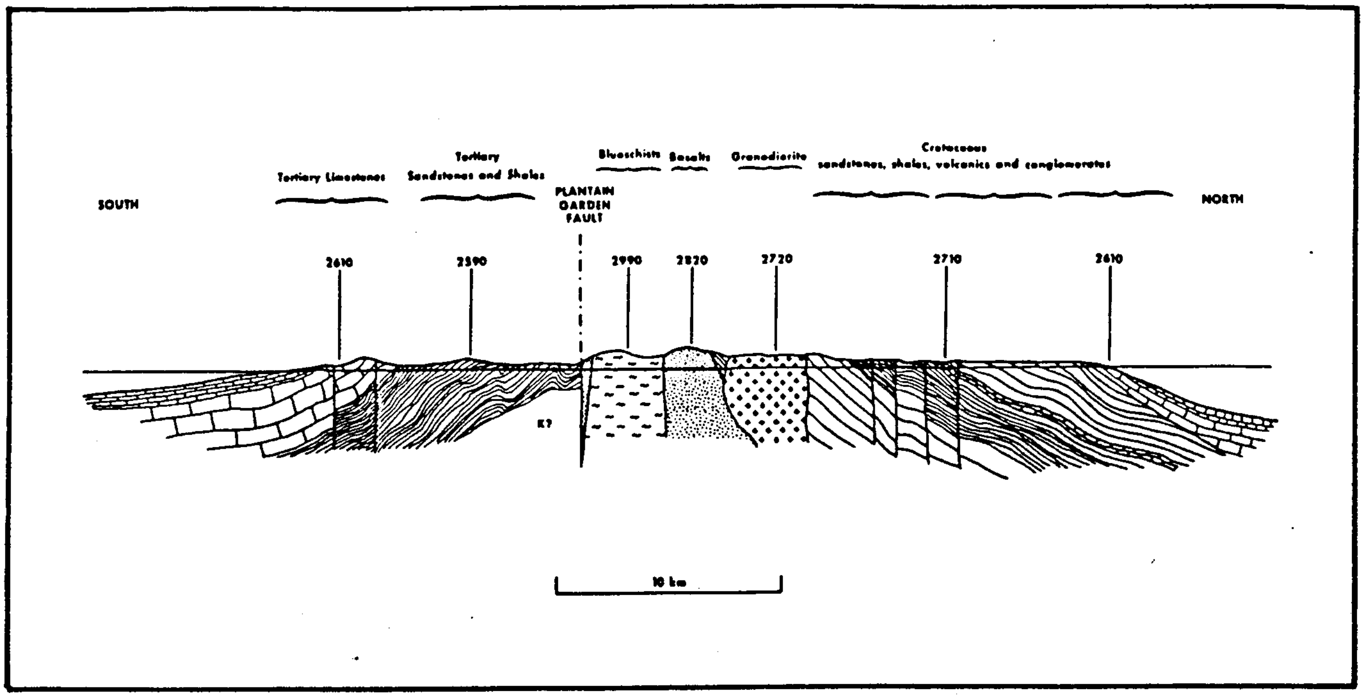

Figure 5. Schematic geologic cross-section (AA') through eastern Jamaica to illustrate the general structure, relative positions and densities of the main Rock-Types.

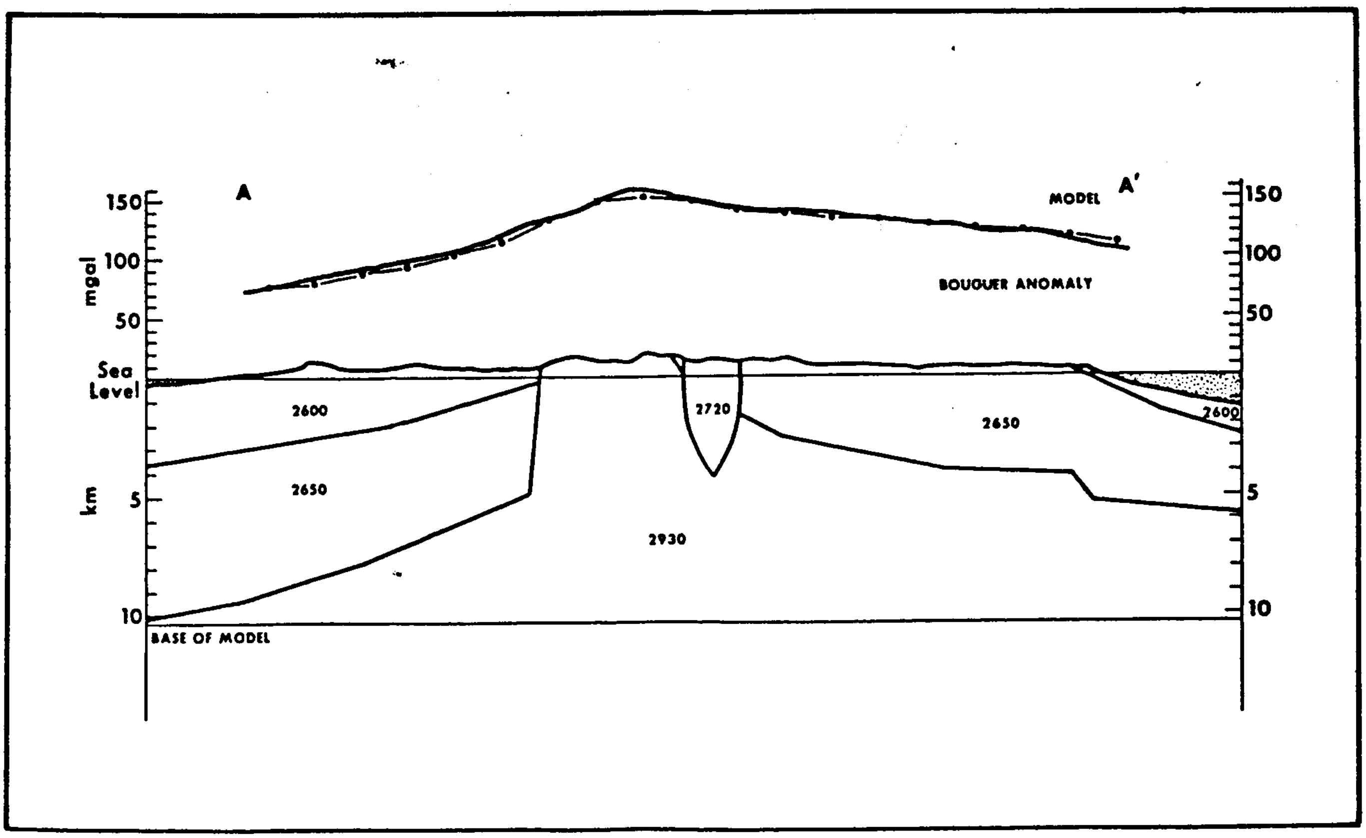

Figure 6. Two dimensional structure model of eastern Jamaica, compatible with the Bouguer gravity anomaly profile along line AA in figure 4. Choice of rock densities is discussed in the text.

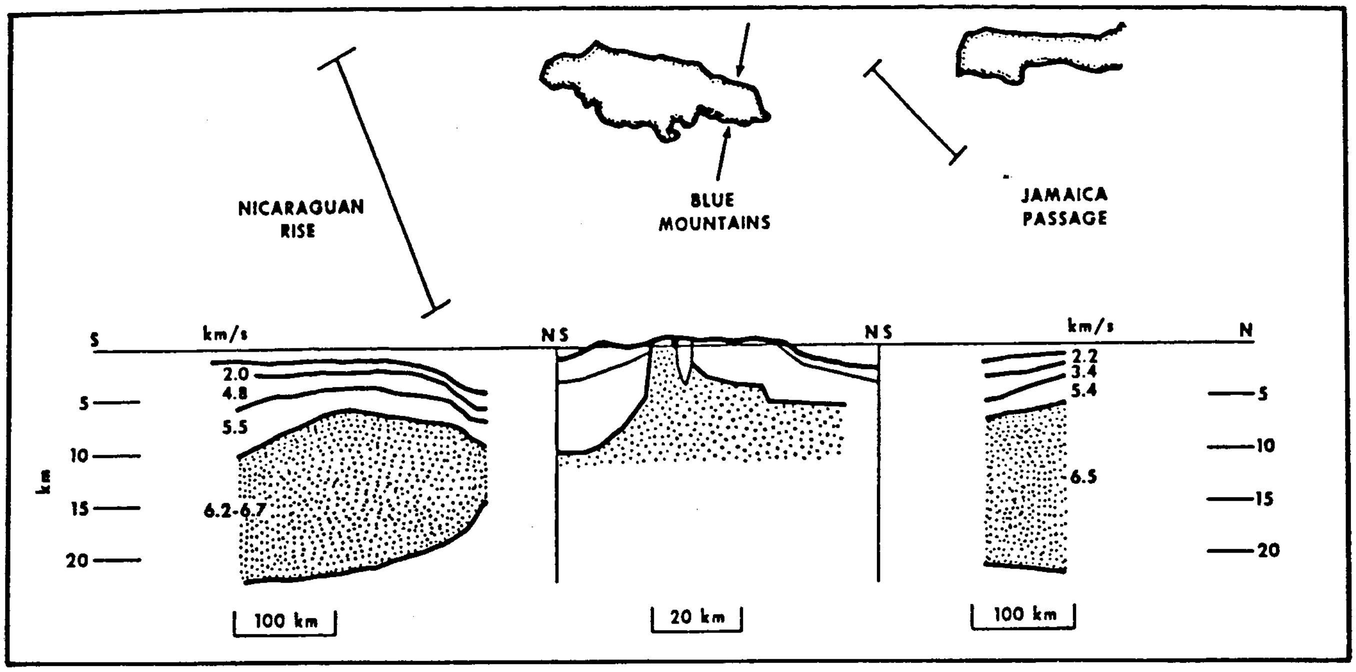

Figure 7. Comparison of seismic refraction profiles on the Nicaraguan Rise and Jamaica Passage (Ewing *et al.*, 1969) with the structure model of figure 6.

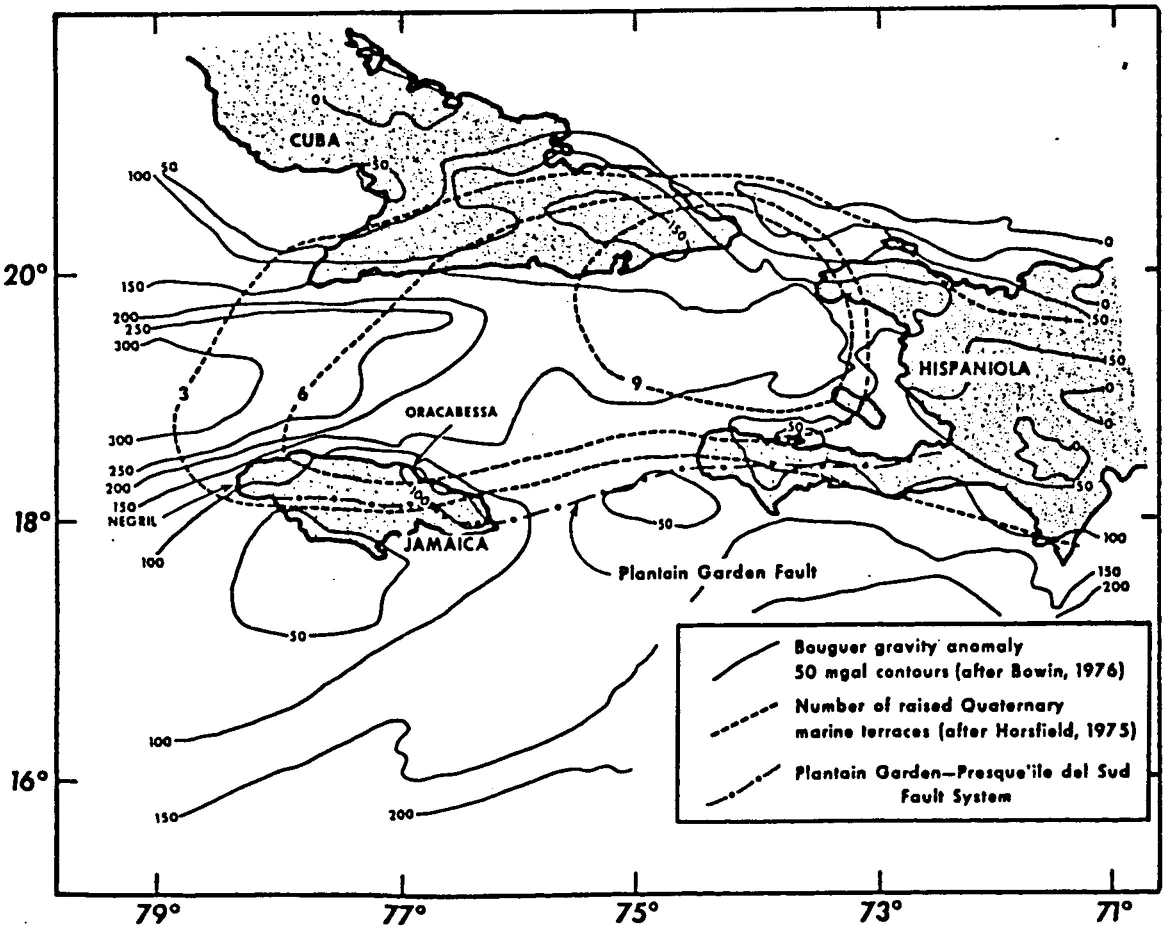

Figure 8. Map of the eastern Cayman Trough region to illustrate the position of the Blue Mountain positive gravity anomaly relative to the Plantain Garden-Presque'ile du Sud fault system. Also shown is the correspondence between the major on-land positive gravity anomalies (after Bowin, 1976) and the number of raised Quaternary marine terraces (after Horsfield, 1975).